

The Future of Crop Protection

By Dr Liliya Serazetdinova

Knowledge Transfer Manager, KTN Agri-Food Team

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Introduction

The use of pesticides in agriculture can be a controversial discussion point. Pesticides have a significant role to play in increasing agricultural production around the world and improving food safety. However, due to an increasing awareness of potential adverse effects of pesticides on the safety of foods and on the environment, a shift from scientific to political influence, and from risk-to hazard-based assessment, regulatory bodies in the EU are now increasingly restricting their use. This in turn limits the range of chemicals that farmers can use to control pests and diseases as well as when and where they can be used.

The development of new and safer pest control methods, including alternatives to widely used chemical pesticides, has become a serious priority for the entire agrifood industry. This paper provides examples of some novel approaches for crop protection that have the potential to become more mainstream in the future, and UK companies that are developing them.



Current state of the crop protection market

Pesticides have contributed significantly to improving agricultural production worldwide, increasing both yield and quality, and driving growth in agricultural income, particularly in developed countries¹. The global crop protection market is estimated to be worth £45bn and growing with pesticides accounting for 90% of the market². At least 20% of our world productivity is currently lost due to insect attack³. Without fungicides, yields of most fruits and vegetables would fall by 50–90%, making fresh produce unaffordable to many⁴.

Crop breeding plays a significant role in improving resistance of crops to pathogens and diseases, and reduces the need for crop protection. Aside from classical breeding, there has been much interest in the use of advanced breeding techniques, including agricultural biotechnology, to introduce insect and disease resistance and herbicide tolerance into major crop plants. This has been very successful in many parts of the world, but commercial activity in Europe is limited due to GMO regulation.

Balanced against the productivity gains, there are significant issues associated with use of pesticides globally. There is a growing

awareness of the adverse effects of pesticides on the safety of foods and on the environment, including health risks to humans and other living organisms, and the persistence of these chemicals in the environment. In addition to this, pests can develop resistance to commonly applied chemicals, for example, more than 500 arthropod pests worldwide have developed resistance to insecticides in the last 50 years⁵. In part, these negative environmental impacts and build-up of resistance are exacerbated by over-use and incorrect application of chemical crop protection.

The European Union is responding to this by adopting the Integrated Pest Management (IPM) approach to control of pests and disease. An IPM approach indicates use of chemicals only as a last resort. The first line of defence is seen through agronomy (crop rotation, cultivation methods and farm management to encourage beneficial organisms) and natural or bred-in resistance. The European Directive 2009/128/EC aims to achieve the sustainable use of pesticides in the EU by reducing the risks and impacts of pesticide use on human health and the environment. The directive also aims to promote alternative approaches or

1. Graham Matthews. The History of Pesticides. Boston, MA: CABI, 2018. ISBN 9781786394873

2. Syngenta report “Our Industry 2016”

www.syngenta.com/~media/Files/S/Syngenta/our-industry-syngenta.pdf

3. nEUROSTRESSPEP project brochure

neurostresspep.eu/img/homepage/nEUROSTRESSPEP_Project_Brochure.pdf

4. Syngenta report “Our Industry 2016”

www.syngenta.com/~media/Files/S/Syngenta/our-industry-syngenta.pdf

5. CropLife International, April 2007. Insecticide Resistance Action Committee. Resistance Management for Sustainable Agriculture and Improved Public Health.

www.irc-online.org/documents/irc-croplife-irm-booklet



techniques, such as non-chemical alternatives to pesticides.

The current EU legislation is increasingly adopting a hazard-based precautionary approach, rather than a risk-based approach to the use of crop protection products in Europe. The hazard-based approach is used to deal with potential risks to human health and the environment, even when there is little or no exposure, or no scientific evidence to prove a causal link between the potential stressor and the effect. In risk assessment, it is important to distinguish between hazard (the intrinsic potential to cause harm), and risk (the probability of harm occurring at a given exposure). In hazard assessment, all the context is removed. Furthermore, even within the context of risk assessment, new classes of molecules, that may have completely new ways of acting, may be hard to register due to the risk perceptions by regulators. If assessment panels consist of non-specialists (which will be normal for new molecules), then the level of uncertainty may be perceived to be higher than for more familiar molecules where the context is better established. In addition, the new regulation for pesticides introduced in 2009 (1107/2009) led to the adoption of 'cut-off criteria'. Certain hazard criteria or properties, like environmental persistence, bioaccumulation or toxicity in a laboratory trial, are invoked to eliminate substances from further consideration as possible tools

for agriculture if a certain threshold value is reached, without consideration of the actual risk of use in practice.

As a result of growing consumer concerns and regulatory pressure, farmers are increasingly facing a reduction in the range of crop protection chemicals they can use. A recent report estimates that 87 of the 250 active substances currently approved in the UK could be lost due to an increasingly challenging regulatory environment⁶. For example, of the 108 insecticides authorised for use in the EU, 43 will expire within the next two years and a further 29 active ingredients will be removed within the next five years. In the UK, fungicides represent a greater market than insecticides, and these face similar pressure with 12 substances from 31 registered fungicides highly likely to be lost or restricted, and these withdrawals will have a significant impact on UK cereal production⁷. Withdrawal of major pest control substances has serious economic impacts on growers. For example, the neonicotinoid ban has cost the European Oilseed Rape farming industry €900 million a year, according to a study commissioned by Bayer and Syngenta⁸.

All these factors together suggest that the development of new and safer pest control methods, including alternatives to widely used chemical pesticides, has become a serious priority for the entire agrifood industry.

6,7. NFU, AIC, CPA (2014). The effect of the loss of plant protection products on UK agriculture and horticulture and the wider economy. www.nfuonline.com/andersons-final-report/

8. European Crop Protection association website www.ecpa.eu/news/new-study-shows-neonicotinoid-ban-has-cost-european-oilseed-rape-farming-industry-%E2%82%AC900-million

Crop protection solutions

Current pressures on the agrifood supply chain, together with the high cost of development, are forcing the agrochemical industry to refocus their strategy for new product development and incorporate sustainability factors in the design, manufacture and use of pesticides.



A number of diversification and alternative strategies are being pursued by the crop protection industry and “new entrants”, which has resulted in a plethora of new solutions coming to our attention. There are however considerable market, legislative and practical barriers to the development of alternatives, i.e. the substantial and increasing cost of developing and bringing to market classical agrochemicals with new modes of action, the challenges in manufacturing and development processes for effective biological alternatives, on-going regulatory issues around use of GM and advanced breeding technologies, and public opinions of new technologies. Examples of these innovative strategies, and companies developing them are described in this paper.

Extending the use of existing agrochemicals

The overall costs of discovery and development of a new crop protection product has increased from \$152 million in 1995 to \$286 million in 2014. The total registration-related costs of developing a new active ingredient has more than doubled in nominal terms between 1995 and 2014 to around

\$100 million, 34% of the total cost of developing a new product⁹. As a result, the number of new agrochemical products being introduced into the EU market per year is declining^{10,11}.

9. Phillips McDougall (2018). Evolution of the Crop Protection Industry since 1960.

agribusinessintelligence.informa.com/~media/informa-shop-window/agri/images/sample-content/reports/pmd_evolution_of_the_crop_protection_industry.pdf

10. Agbioinvestor (2018). “The Challenges Facing Agriculture and the Plant Science Industry in the EU”

www.europabio.org/agricultural-biotech/publications/challenges-facing-agriculture-and-plant-science-industry-eu

11. Phillips McDougall (2018). Evolution of the Crop Protection Industry since 1960

agribusinessintelligence.informa.com/~media/informa-shop-window/agri/images/sample-content/reports/pmd_evolution_of_the_crop_protection_industry.pdf



The increasing cost, complexity and uncertainty around registration of new patented crop protection active ingredients, together with the need to produce food at affordable prices while controlling pests and diseases, has encouraged the crop protection industry to introduce cheaper generic pesticides as soon as they come off-patent. Companies commercialising generics focus their efforts on volume, price and breadth of label. Where possible, they seek to improve the breadth of application of a given compound in the field, or identify new crops or geographic regions that can benefit from off-patent compounds.

A recent study in France published in *Nature Plants* demonstrated that low pesticide use rarely decreases productivity and profitability in arable farms. The study analysed data from 946 non-organic arable commercial farms and showed that total pesticide use could be reduced by 42% without any negative effects on both productivity

and profitability in 59% of farms analysed. This corresponded to an average reduction of 37, 47 and 60% of herbicide, fungicide and insecticide use, respectively¹².

Improved scouting and changes to agronomy can help to maintain productivity and profitability even with reduced use of pesticides. If the majority of growers were able to invest time and resources in these interventions, use of pesticides in agriculture could be significantly reduced. One way of reducing the quantity of pesticides used is to ensure that the pesticide only reaches its intended target. However, in practice this is hard to achieve and much of a broadcast spray application is wasted. Reduction of spray drift is one of the most important factors within the control of the grower, and can be achieved through optimising the droplet size, pressure, sprayer equipment height and forward speed to suit the type of crop and environmental conditions. Products are frequently formulated with adjuvants to reduce drift and ensure that the droplets stick to leaves, and applied with special nozzles to direct the spray to the intended target. Targeted application can also be improved through better diagnostics and crop management approaches using sensors, drones and robotics. These precision engineering approaches are described below in the section “Precision Agriculture Approaches”.

Another approach to reviving the activity of older active ingredients, that have become ineffective due to pests developing resistance to them, is based on the use of synergists or “primers”

12. M. Lechenet et al. (2017). Reducing pesticide use while preserving crop productivity and profitability on arable farms, *Nat. Plants*, 3:17008, 2017 doi.org/10.1038/nplants.2017.8

that counteract metabolic pesticide resistance in pests. The mode of action of the majority of synergists is to block the metabolic systems that would otherwise break down insecticide molecules. This approach is being pursued by a company called Pangaea Agrochemicals Ltd (pangaeaagrochemicals.co.uk), which is developing a portfolio of crop-protection products based on existing active ingredients

in combination with patented technology that overcomes pesticide resistance¹³. This technology could potentially “revive” a range of agrochemicals used for weed, insect, and fungal control. However, there are some concerns among regulators that these synergists may affect metabolic systems in other organisms, and cause greater environmental or human safety effects.



Biopesticides

Regulations that promote easier registration of low-risk compounds have encouraged development and commercialisation of biopesticides. Biopesticides are a wide spectrum of plant protection products based on parasites, predators, microbials, pheromones, and plant extracts. Almost 90% of the microbial biopesticides currently available on the market are derived from only one entomopathogenic

bacterium, namely *Bacillus thuringiensis* or BT¹⁴.

Currently, biopesticides comprise a relatively small market share, approximately 5-10% of the total crop protection market globally, with a value estimated around \$3 billion worldwide^{15,16,17}. However, over the last 20 years the rate of new biological product introduction has frequently exceeded that of conventional products¹⁸. It is

13. International patent application WO2016193704A1. A primer for pesticides.

patents.google.com/patent/WO2016193704A1/en

14. Kumar S. and Singh A. Biopesticides: Present status and the future prospects. *Journal of Fertilisers and Pesticides* 2015, 6, e129. [doi:10.4172/2471-2728.1000e129](https://doi.org/10.4172/2471-2728.1000e129)

15. Marrone, P.G. The market and potential for biopesticides. In *Biopesticides: State of the Art and Future Opportunities*; Gross, A.D., Coats, J.R., Duke, S.O., Seiber, J.N., Eds.; American Chemical Society: Washington, DC, USA, 2014; pp. 245–258.

16. Olson, S. An analysis of the biopesticide market now and where is going. *Outlooks Pest Management* 2015, 26, 203–206, doi.org/10.1564/v26_oct_04

17,18. Phillips McDougall (2018). Evolution of the Crop Protection Industry since 1960.

agribusinessintelligence.informa.com/~media/informa-shop-window/agri/images/sample-content/reports/pmd_evolution_of_the_crop_protection_industry.pdf

forecast that biopesticides will grow substantially and equalize with synthetics in terms of market size between the late 2040s and the early 2050s¹⁹.

A potential shortcoming of biopesticides is their efficacy at scale and over multiple years. There is still a great variability with effectiveness of biopesticides, with some growers achieving 80% while others less than 50% reduction in pests and disease. Key barriers to achieving a wider use of biopesticides are the need to change working practices (particularly scouting and application methods), their formulation stability and residual action. Nanoformulations and microencapsulation technologies have been reported to improve the stability and residual action of biopesticide products²⁰. Awareness-raising among farmers and training, as well as development of reproducible and effective application methods could further increase their adoption.

Biopesticides are already seen as viable commercial solutions in the horticulture industry producing high value crops, mostly under controlled glasshouse environments which are



conducive to the use of biologicals. This subsector of agriculture benefits from higher profit margins but has very high quality standards, with low tolerances for agrochemical residue levels and high visual appeal, driven by the value chain and consumer requirements. This industry is seen as the first adopter of biopesticides.

Major agrochemical companies are developing and marketing biopesticides, including BASF, Bayer, DowDuPont (Corteva Agriscience), and Syngenta (part of ChemChina). Over 130 companies are listed as members of the Biological Products Industry Alliance (BPIA)²¹, for fostering continued improvements to the biological products regulatory process. European companies Bioline AgroSciences Ltd (formerly Syngenta Bioline) and Koppert are seen as market leaders in developing a range of micro-organisms, biostimulants and pheromones.

The two most common types of biopesticide products on the market are bacterial entomopathogens such as BT and insect traps that use semio-chemicals that attract insects (pheromones). Russell IPM Ltd (russellipm.com) market a range of bio-rational pest control solutions for the soft fruit industry in developing countries. Russell IPM products utilise pheromone based attractants and are compatible with integrated pest management and sustainable agricultural intensification. The use of Russell IPM attract and kill systems in Bangladesh has enabled farmers to reduce fruit fly infestation by 68% in mango, by 83-88% in guava, and by 88-91% in bitter melon, compared to untreated plants²². Insect parasitic nematodes are another type of biopesticide products that

19. Olson, S. An analysis of the biopesticide market now and where is going. *Outlooks Pest Manag.* 2015, 26, 203–206, doi.org/10.1564/v26_oct_04

20. Damalas C.A. and Koutroubas C.D. Current Status and Recent Developments in Biopesticide Use. *Agriculture* 2018, 8, 13; [doi:10.3390/agriculture8010013](https://doi.org/10.3390/agriculture8010013)

21. Biological Products Industry Alliance website www.bpia.org

22. KTN case study (2017). Creating new opportunities for sustainable fruit and vegetable production in Asia and Africa

ktn-uk.co.uk/news/creating-new-opportunities-for-sustainable-fruit-and-vegetable-production-in-asia-and-africa

are gaining interest. The UK company Bionema Ltd (bionema.com) develops products to control a range of pest insects and worms in soft fruits, ornamentals and flowers, sports turf, forestry,

and mushroom cultivation. Their NemaTrident® Tri-Component System based on insect parasitic nematodes provides 70-100% kill rates in a range of horticultural applications²³.

Biological solutions

There are a number of other solutions being developed by industry and academia aiming to provide alternatives to chemical control, which are not yet commercialised. They are following the path of biopesticides, whereby the body of evidence of their efficacy and safety needs to grow while end users, farmer and consumers, and regulatory bodies recognise these new solutions as part of the existing practices.



Peptide hormones

One novel approach utilises our understanding of endocrine control in insects. Peptide hormones regulate key biological processes in all vertebrate animals, including insects. Hormonal peptides regulate many aspects of insect physiology and development, including feeding, growth, and reproductive behaviour. These peptides can selectively disrupt specific physiological processes, and thus reduce survival and reproduction of target (pest) species. These “special agents” or their synthetic analogues, mimetics, agonists or antagonists may be more effective tools in combating insect pests in an environmentally sound manner than the use of conventional pesticides.

Potential peptide targets have recently been discovered that could be used to control the highly invasive *Drosophila suzukii*, a serious pest of soft fruits²⁴. The EU funded project nEUROSTRESSPEP, led by the University of Glasgow, aims to develop novel, insect species specific biocontrol agents based on the use of peptides that interfere with pest insect neurological functions while leaving non-pest species unaffected. The project aims to develop novel agents that will target specific pest insects of cereals, horticultural crops, vegetables and forestry²⁵.

23. Company website, bionema.com

24. Gough CS etc. (2017). Peptidergic control in a fruit crop pest: The spotted-wing drosophila, *Drosophila suzukii* doi.org/10.1371/journal.pone.0188021

25. nEUROSTRESSPEP project brochure (2018).

neurostresspep.eu/img/homepage/nEUROSTRESSPEP_Project_Brochure.pdf

RNAi

Several companies are pursuing gene silencing approaches to “switch off” the genes responsible for survival and spread of pests, pathogens and diseases. All genetic information in living organisms is encoded in DNA (a double stranded helix of polynucleotides), while the expression of individual genes is regulated by a messenger RNA (mRNA, a single stranded polynucleotide molecule). RNA directly regulates the protein-making machinery in the cell. RNA interference (RNAi) is a means of reducing or switching-off the expression of individual genes, often described as ‘gene silencing’. RNAi is a natural process with important defence and regulatory functions in animals, plants and fungi, which is enabled by a double-stranded form of RNA (dsRNA). dsRNA activates biochemical machinery that degrades messenger RNA molecules (mRNA) carrying a genetic code matching that of the dsRNA. When such mRNA molecules are ‘interfered with’ and degraded, the corresponding gene is effectively silenced and no protein from that gene is made. In the crop protection and seeds industry to date, RNAi technology has been employed in GM crops, as a tool in breeding improved crop varieties and in experiments investigating new pesticides’ modes of action²⁶.

If delivered via spray (exogenous application), RNAi could be applied in the same way as normal chemical pesticides by spraying them on the plants. Therefore, RNAi technology for crop protection attracted attention of major agrochemical companies, like Syngenta, a pioneer in the field with the development of a sprayable RNA biocontrol portfolio to control insects. The practical and commercial viability of spraying crops with dsRNA has yet to be demonstrated, and the search for new delivery mechanisms into pests, pathogens and into the plant cell is ongoing.

Start-up company CropVax Ltd (cropvax.com) claim to have developed a platform that can deliver RNAi into crops. This new form of pesticide (referred to as vaccines) could be produced in a very short period of time whilst being cost effective compared to current chemical pesticides. Although CropVax technology has the potential to fight against the most challenging pathogens, this technology has not yet been demonstrated to work at scale.



26. Dr Alan Baylis, SCI (2017). RNAi technology in crop production.
www.soci.org/news/general-news/rnai-technology-in-crop-production

Gene editing



Gene editing is a group of techniques that enable us to change an organism's DNA, including insertion, replacement or removal of DNA from a genome with a high degree of specificity. Several approaches to genome editing have been developed. One of the most widely used is known as CRISPR-Cas9, which is short for clustered regularly interspaced short palindromic repeats and CRISPR-associated protein 9. CRISPR-Cas9 was adapted from a naturally occurring genome editing system in bacteria. The bacteria capture snippets of DNA from invading viruses and use them to create DNA segments known as CRISPR arrays. The CRISPR arrays allow the bacteria to "identify" the viruses and target the viral DNA, the bacteria then use Cas9 or a similar enzyme to cut the DNA apart, which disables the virus. Gene editing has a significant potential to improve specific plant traits (and quality of plant raw material), or confer resistance to pests and diseases. Use of CRISPR-Cas9 technology has revolutionised non-GM breeding since its adoption in 2012.

Start-up company Phytoform Labs Ltd (phytoformlabs.com) aims to commercialise gene editing technologies for the horticulture sector and speed up the development of new varieties with enhanced pest and disease resistance, or improved quality traits. They are developing a new unique breeding platform based on the use of genomics, gene editing tools and proprietary automated screening technology. If proven to

work, this platform could significantly reduce the breeding cycle and provide significant cost savings for plant breeders.

Tropic Biosciences Ltd (tropicbioscience.com) uses advanced genome-editing technologies to develop improved commercial varieties of tropical crops, namely coffee and bananas, with the aim of improving crop production as well as nutritional and processing characteristics. The company is also developing highly innovative molecular approaches that will support development of new varieties for a wide range of crops. The new approach has the potential to address some of agriculture's greatest remaining challenges, such as Black Sigatoka Disease in bananas which causes 50% yield losses, requires fungicide application 20-70 times/year, and increases the production costs by 25%²⁷.

Recently, a hurdle has been placed in the way of rapid commercialisation of these technologies in Europe as the European Court of Justice (ECJ) ruled in July 2018 that organisms obtained by gene editing techniques are subject to the same regulations as genetically modified organisms (GMOs). This means that crops that are bred using gene editing would need to go through the lengthy European Union approval process materially affecting the likelihood of commercial deployment of such crops in the EU. In the US, the United States Department of Agriculture (USDA) announced that it has no plans to regulate genome editing when used to produce new plant varieties that are indistinguishable from those bred through traditional breeding methods. The ECJ ruling also represents a threat to companies outside of the EU producing crops using gene editing that are subsequently imported into the EU. Overall, much of the potential of these innovative methods is likely to be lost for Europe.

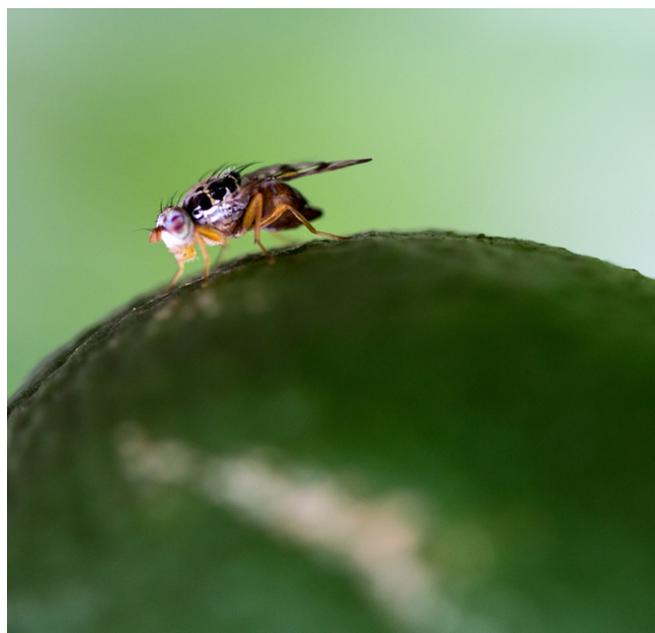
27. Tropic Biosciences, personal communication

GM insects

The genetic engineering of insects to reduce populations or to replace them with less harmful varieties is a new control method for insect pests. Genetically modified (GM) insects are produced by inserting new genes into their DNA. Many genes have been identified that can alter the behaviour and biology of insects, including lethal genes that cause the insect to die, or make it unable to reproduce. The advantages of GM insects include high specificity to a single insect pest species, and the potential to reduce the need for insecticides and any associated toxic residues in the environment.

UK company Oxitec Ltd (oxitec.com) is pioneering the development and use of self-limiting gene technology to control insects that spread disease and damage crops. Oxitec has developed a self-limiting mosquito carrying a gene that results in non-viable offspring, to control malaria and Zika virus. Similar technology can be deployed to crop pests such as diamondback moth (a pest causing serious damage to brassicas including oilseed rape), spotted wing drosophila (a serious insect pest for soft and stone fruits), fall armyworm (one of the most invasive and polyphagous crop pests), and Mediterranean fruit fly (that attacks a wide range of fruits, flowers, vegetables). Oxitec believes this approach provides environmentally friendly pest control by targeting only one insect pest and allowing other insects, like bees and butterflies, to thrive²⁸. Trial releases of GM insects for disease control have now been conducted in the Caribbean, Malaysia, and Brazil, but none have yet proceeded in the European Union (EU).

In the EU, applications to release GM insects are assessed under Directive 2001/18/EC²⁹, known as the Deliberate Release Directive, which regulates deliberate release of all GMOs into the environment. Spain, France, and the Netherlands were considering trials of Oxitec GM insects. The European Food Safety Authority (EFSA) has produced guidance on the risk assessment of GM insects for commercial use in the EU²⁹. In the UK, the decision to approve non-commercial releases of GMO insects, for example in a field trial, is made by the Department for Environment, Food and Rural Affairs (DEFRA) in consultation with the independent scientific experts of its Advisory Committee on Releases to the Environment (ACRE), which is responsible for assessing the risks of the technology. For commercial release, DEFRA would perform an initial evaluation of the application with ACRE's input. This application would then be sent to every EU member state, with the European Food Safety Authority (EFSA) providing a scientific opinion.



28. Oxitec website www.oxitec.com/our-technology/

29. EFSA Panel on Genetically Modified Organisms (2013). Guidance on the environmental risk assessment of genetically modified animals. publications.europa.eu/resource/cellar/89edf3af-721a-4e2b-a95b-3af22548ff7f.0001.02/DOC_1

The current regulatory framework has numerous limitations in its application for GM insects. The ecological risks and hazards associated with the release of GM insects are 'product' specific; i.e. the GM technology, species, lifecycle, locality, and time of year, will all impact on the ecological consequences of its release. There is increasing pressure from both researchers and companies developing GM insects to review the regulation in the context of insects, and carry out assessments on a case-by-case basis, taking into account

both the benefits and the risks of the release³⁰. Regional differences in the assessment criteria also reflect public opinion³¹. When assessing new technology, regulators should consider the balance of risk and benefit resulting from GM insect release, not risk alone, and make this process more transparent. Engagement with the communities that will be affected by GM insects is needed if the technology is to be embraced by the public and eventually deployed.

30. British Ecological Society (2015). Genetically modified insects: A response from the British Ecological Society to the House of Lords Science & Technology Committee

www.britishecologicalsociety.org/wp-content/uploads/GM-Insects_BES-Response_Final.pdf

31. Panjwani A, Wilson A (2016) What Is Stopping the Use of Genetically Modified Insects for Disease Control? PLoS Pathog 12(10): e1005830 doi.org/10.1371/journal.ppat.1005830

Novel solutions inspired by technologies originating from other disciplines

There are a growing number of technologies that are based on “physical” approaches rather than those above based on biological processes. Agriculture presents a very attractive and large market for some technologies that have been proven to work in other industries.

A range of technologies are being brought into agriculture that may provide an important part of IPM including flaming, steam treatment,

electrocution, applying electrostatic fields, microwave weed treatment, applying infrared or ultraviolet radiation, using lasers, robotics, and abrasive weed control techniques³². Key barriers for adoption of these technologies include provision of cost effective and safe energy sources, end-user centric product design and integration with existing crop monitoring and management processes.

Precision agriculture approaches

Precision agriculture is seen as an important tool in building a commercially viable and sustainable crop protection strategy minimising the amount of agrochemicals used, potentially extending the functional life of existing and new control agents and providing cost savings to farmers. A more targeted application of existing (and novel) pest control agents can also reduce the build-up of resistance to chemicals in pests, minimise soil compaction from heavy machinery, and help address labour shortages.

Pre-symptomatic disease detection is one of the most powerful approaches to direct crop protection treatment and improve crop yield outcomes. There are many remote sensing and in-field diagnostic approaches being developed by academic groups and start-up companies, and validated by agronomists and growers.

HummingbirdTechnologiesLtd(hummingbirdtech.com) is a remote sensing business that uses artificial intelligence technologies to gather information from drones, planes and satellites, combined with weather and soil data and expert plant pathology input, to enable pre-symptomatic



32. Graham Brodie (2018). Chapter 3 - The Use of Physics in Weed Control. In: Non-Chemical Weed Control. pp 33-59 doi.org/10.1016/B978-0-12-809881-3.00003-6

detection of crop diseases. This early detection is based on a technique called Normalized Difference Vegetation Index (NDVI). Healthy plants strongly reflect NIR (near infrared) light, when a plant is diseased or weak, reflection of NIR is greatly reduced. The infrared images are processed using software to create the NDVI, which can then identify the affected areas with pinpoint accuracy³³.

Another example of a remote sensing approach to crop protection is spore trapping technology. Spore traps act as early indicators, detecting the presence of fungal spores in the air before infection takes place and before symptoms are visible in the field. Spore traps can be made in different ways, from passive, to rotor rod or air suction traps. Passive traps collect rain or wind that pass through certain type of cassettes (filters) designed to catch spores based on their size. The spores are extracted from the cassette and then identified visually or by the use of molecular techniques, for example, by quantitative Polymerase Chain Reaction (qPCR) or by fluorescence, which can distinguish between different fungal varieties and can quantify the level of infestation. Spore traps can help growers and agronomists to monitor the pathogen's airborne inoculum and forecast the probability of infection based on weather conditions, and so could help reduce the use of fungicides. For example, a spore trapping prototype is under development for forecasting potato late blight infestations to enhance decision making for growers with respect to fungicide choice and application encouraging more efficient resource use³⁴.

FungiAlert Ltd (fungialert.com) is developing in-field early detection sensors for fungal diseases



that can detect live and actively growing microorganisms in the field, enabling disease pressure forecasts for particular crops and across different seasons. The device transmits its readings wirelessly allowing real-time alerts to be sent to growers.

Househam Sprayers Ltd (househamsprayers.co.uk) is incorporating a range of technologies to optimise and automate crop spraying, including GPS field mapping, individual nozzle control, boom levelling, auto nozzle select, autosteer and remote diagnostics. Importantly, these have been designed to integrate with most common crop management software. Other innovations to increase precision application of pesticides include targeted variable rate spraying, electrostatic spraying, air inclusion nozzles, low and ultra-low volume spraying with rotary discs, applications to trees, crop adapted spraying, recycling spraying in vines, direct injection systems, rope application of herbicides, and vertical spray booms for greenhouse use³⁵.

A number of other precision approaches to improve crop protection are being piloted,

33. Agri-Tech East website article "Hummingbird takes flight with early crop health monitoring", published 20 January 2017

www.agritech-east.co.uk/hummingbird-takes-flight-with-early-crop-health-monitoring/

34. Gateway to Research database. Project reference 102099. gtr.ukri.org/projects?ref=102099

35. Keith Jones. Presentation "Enhanced efficacy, efficiency and safety through improved application" www.oecd.org/chemicalsafety/pesticides-biocides/37237992.pdf

including use of satellite imaging and drones to map areas affected by pests and disease and the use of autonomous robots for weeding and crop protection product application.

A recently funded joint project GrassVision³⁶, will use novel 3D machine vision and precision agriculture techniques to apply herbicides to broad-leaf weeds in grass crops, aiming to achieve reductions in herbicide use in excess of 90%. This is a collaboration between imaging experts at the Centre for Machine Vision, University of West England, data analysis experts at Aralia Ltd and precision agriculture experts at SoilEssentials Ltd.

Start-up company Small Robot Company Ltd (smallrobotcompany.com) takes this vision even further by combining the power and precision of robots with the power of Artificial Intelligence (AI). They are developing specialised farming robots that could carry out feeding, seeding, and weeding autonomously, helping to reduce the use of agrochemicals by up to 95%. Their concept



is to develop a farming service whereby a robotic fleet will be shared by several farms and help to reduce the costs associated with expensive capital equipment, as well as reduce risks associated with uptake of this new technology.

Magnetic induction heating

Electromagnetic induction heating is a technology that has many applications in metal working and plastic processing. Induction heating allows the targeted heating of an object. It is also used in everyday applications such as induction hobs in kitchens.

A start-up company Agri-Induction Ltd is developing an application of high-frequency magnetic heating to kill invertebrate pests³⁷. The approach relies upon the significant differential

in electrical conductivities between plants and animals. This technology is likely to find initial application in nurseries with high value produce to control vine weevil larvae, and in post-harvest storage to control pests, where damage to beneficial organisms is lowest. Potentially, when this technology is proven to work at scale and integrated with appropriate strategies to avoid damage to beneficial organisms (in soil and on plants), it can be deployment in a wider range of field applications.

36. Gateway to Research database. Project Reference 132339 gtr.ukri.org/projects?ref=132339

37. InnovateUK funded project. New wide-area radio frequency heating method for killing agricultural pests gtr.ukri.org/projects?ref=103309

Electricity

A high-voltage electric current creates a rapid heating effect and causes plant tissues to burn out. The key advantages of the technology are that it is chemical free, systemically kills the roots, does not disturb the soil and is effective for any weed. Ubiquitek Ltd (ubiquitek.com) utilises electricity

to control weeds and has commercialised this technology for use by amateur gardeners. A German company Zasso GmbH (zasso.eu) is taking this innovation further by developing a mounted application which uses a sensor and/or camera-based guidance system.



Hot foam

Use of hot water to kill weeds is a well known non-chemical control used by amateur and professional gardeners. UK company Weedingtech Ltd (weedingtech.com) developed commercial applications based on the precise application of hot water and a biodegradable foam made from natural plant oils and sugars. Hot foam is more effective than hot water as foam

gets the heat into the plant faster, more precisely, keeps the heat on the plant for longer and reduces the amount of hot water needed. Effectiveness of hot foam has been demonstrated in the amenity sector and could become commercially viable in horticulture markets if combined with automated vision and robotic solutions.

The way forward

The agrifood sector recognises the need to integrate existing and new solutions with decision support systems to deliver measurable and sustainable impact on crop protection. There is a need to identify real issues, the best solutions to address them and then change cultural practices.

There is a strong need for partnerships among academia, start-ups, larger agrochemical companies, farmers, regulators, funders, and training providers to develop any integrated solutions. One example of a partnership between the pesticide industry and application equipment manufacturers is a collaboration between John Deere and BASF aiming to integrate BASF's new field scouting and agronomic decision support service with John Deere's application for sprayer setup and use of field data³⁸.

Looking at the technological improvements that will enable wider adoption of new approaches, application routes and delivery systems are seen as critical for some of these novel approaches. Development of optimal application techniques requires a compromise between differing requirements – formulation possibilities, engineering limitations, and crop management strategies. Demonstrating efficacy in commercial field trials is critical for converting emerging crop protection solutions from niche into main stream. Public and private funding will be crucial in de-risking new technologies and raising the awareness among end users and food consumers.

Digitalisation of the agrifood supply chain is affecting crop protection substantially. Use of historical and real time data on pest and disease occurrence, together with data on climatic and soil conditions, has the ability to deliver better management decisions. Another trend supported by the use of digital technologies is that the agrochemical industry is increasingly looking to bypass wholesale trade (distributors) and sell direct to growers with the help of digital tools and new direct-marketing channels, offering direct product support via dedicated apps for farmers. At the same time, use of digital tools and open data enables small innovators to better understand and respond to end user needs, thereby increasing their competitiveness.



38. BASF press release 17 December 2013. John Deere and BASF partner to develop sustainable yield enhancement solutions. agriculture.basf.com/en/Crop-Protection/News-Events/Press-releases/John-Deere-BASF-Partner.html

However, there is still a big gap between innovations and their adoption. The provision of training on practical use of new crop protection solutions, alongside integration with day-to-day farm management processes, will be key to increasing penetration. Non-chemical solutions often require different application techniques and equipment, and their effectiveness is more tightly dependent on climatic and soil conditions, and on the type of planting. It is also important not to overlook the power of public opinion and community practice. Integration of novel solutions requires a significant shift in crop management and agronomy practices, and may even re-balance the power in the agrifood supply chain. Adoption of some novel crop protection approaches will ultimately have an effect on labour and advisory services. It will take time and effort to influence the community best practice in managing crop protection responsively and driving changes in behaviour. It is critical that the capacity to act on disease and pest forecasts (decision support tools) drives different behaviour.



There is also a need to develop supportive policies and blueprints for an IPM-friendly research and legislation landscape. Adoption of IPM by farmers and growers requires a long-term commitment, a shift in expectations and will require more partnerships. Speaking at the 2017 AHDB Agronomists' Conference, Jon Knight, AHDB's Head of Crop Health & Crop Protection, said the long-term plan for IPM should include an improved understanding of soils, full use of plant breeding tools to introduce resistance traits into varieties, development of biopesticides and their application, research into IPM approaches, and optimised use of synthetic chemistry to maximise and protect efficacy³⁹. Examples of this integrated approach are now emerging - the EU funded project DROPSA (dropsaproject.eu) has developed a plethora of practical control solutions for serious diseases of fruit crops including using approved chemicals, new mode of action compounds, semiochemicals, novel antimicrobial compounds, biological control agents as well as cultural practices and sterile insect techniques.

The challenge of increasing productivity whilst reducing environmental impact requires innovation across the agrifood sector. There is a strong need for a shift in approaches for evaluating the effectiveness, commercial viability, environmental and human safety risks as well as benefits. The European Risk Forum (ERF)⁴⁰ is promoting the Innovation Principle to ensure that whenever policy or regulatory decisions are under consideration the impact on innovation as a driver for jobs and growth is assessed and addressed. Policy makers need to fully recognise social and economic needs for both precaution and innovation, and thereby to stimulate confidence, investment and innovation.

39. AHDB (Dec 2017). IPM plan required.

horticulture.ahdb.org.uk/news-item/uk-needs-%E2%80%98coherent%E2%80%99-long-term-plan-ipm

40. European Risk Forum website www.riskforum.eu

The role of KTN

This paper has provided examples of some novel approaches for crop protection developed by UK small companies and start-ups. Outside of the UK, there are many exciting developments as well⁴¹. This sector is opening up a significant new area for investors who are interested in investing in a cross-section of agri-tech focused businesses. The UK has a supportive climate for early stage innovations, but it is more difficult for start-ups looking to demonstrate commercial viability, and secure their first private investment.

There is an ongoing need for private investment in agri-tech to further advance the sustained public investments and technical excellence within the UK, and to enable start-up companies to fund the scale up of their technologies. KTN is providing support to innovative UK companies that have a proven technology and have ambition to grow by identifying suitable grant funding sources, developing partnerships, and helping to access private investment. An example of this work is the KTN Agri-Tech Investment Showcase, an annual activity aiming to support and build this emerging community of early-

stage agri-tech companies and investors. The UK agri-tech investor community is growing, as seen by the growth in interest from our first showcase in 2017 to the event in 2018, including from investors who had not previously invested in agri-tech. There is also a growing supply of early-stage companies looking for investment, with well developed investment propositions⁴².

KTN also plays a key role in building partnerships to support the development and commercialisation of innovative crop protection projects. KTN is a project partner in nEUROSTRESSPEP, mentioned above, providing advice on market needs, enabling stakeholder engagement, and facilitating discussion on exploitation routes⁴³. The project aims to develop novel agents that will target specific pest insects of cereals, horticultural crops, vegetables and forestry.

If your company is developing a new crop protection solution or requiring funding or support with implementing and testing new crop protection solutions, or looking for investors, please speak to the Agri-Food Team at KTN.

41. Alan Baylis (2019). Five innovative small companies in crop protection to watch. www.soci.org/news/general-news/five-innovative-small-companies-in-crop-protection-to-watch

42. David Telford (2019). KTN helps boost investment in UK agri-tech companies ktn-uk.co.uk/news/ktn-helps-boost-investment-in-uk-agri-tech-companies.

43. KTN website article. Using endocrine control in insects to develop new approaches for crop protection. ktn-uk.co.uk/news/using-endocrine-control-in-insects-to-develop-new-approaches-for-crop-protection

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